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STEVENS INSTITUTE OF TECHNOLOGY
DAVIDSON LABORATORY
CASTLE POINT STATION
HOBOKEN, NEW JERSEY

SECOND QUARTERLY PROGRESS REPORT
Hydroplaning of Aircraft Tires

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31-003-016

NASA Contract NSR 31003016

DL Project 475/6

Objective

To make a systematic experimental study of the various parameters affecting hydroplaning of aircraft tires, and to seek a quantitative theoretical description of the hydroplaning phenomenon.

Work Completed During the Period 15 January through 15 April 1965

Modification of the Davidson Laboratory rolling road facility is in progress. As an added safety factor, it has been decided to increase the drive power to 40 hp, instead of the 25 hp originally contemplated¹, and a DC motor of this capacity has been ordered from U.S. government surplus (at no cost to the contract). A 50 kw motor generator set for its control system has also been obtained from the same source and is now being installed.

A 4-inch wide sample transparent belt of .06 inch thick oriented nylon was installed on the rolling road for trial tests. First observations indicated satisfactory performance except for a tendency to oscillate laterally. This tendency appears to be the result of faulty alignment of the belt's transverse joint, and should be avoidable in the full-size belt if sufficient care is taken in the aligning and jointing processes.

A wider sample of the belting material was also obtained, and photographs were taken through it to check its optical properties and establish lighting requirements. These indicated that visual observation and recording of the tire foot print area should be feasible with the oriented nylon belt. Two representative photos taken through the belt are shown in Fig. 1.

The test rig to be used to constrain the model tires on the rolling road and to measure drag and torque is under construction. It was decided that this device could be built most economically using an existing aircraft nose wheel assembly as the basic frame. A used assembly from a Grumman Aircraft Engineering Corporation Mohawk aircraft was donated to Davidson Laboratory by Grumman for this purpose. Instrumentation and other modifications are currently being added.

A system for applying the water film to the rolling road has been designed, components have been ordered, and assembly is underway. It is a closed system consisting essentially of a 37-1/2 cu. ft. capacity reservoir, a 150-foot head centrifugal pump with an integral 25 hp 110V AC power pack, a turbine type liquid flow meter, adjusting valves, and a diverging nozzle with variable exit area. The system is designed to deliver films up to 0.1 in. thick at speeds up to 90 ft/sec., and films up to 0.5 in. thick at proportionally lower speeds. For a geometric scale factor of 5:1 and a Froude number velocity scaling law, these correspond to 0.5 in. thickness, 200 ft/sec. (approximately 120 knots) speed, and 2.5 in. thickness, respectively, at full scale.

Attempts to develop a technique for measuring tire foot print pressure distribution on the rolling road have suffered a setback. The method which had been devised depended upon the use of miniature transducers embedded in the belt. Unfortunately, the only known manufacturer of transducers with the required properties has temporarily suspended operations because of some sort of legal dispute. Efforts are currently being made to circumvent this difficulty.

A simple exploratory experiment was conducted to study static properties of one type of model tire under consideration. A small existing tire rig was modified to accommodate vertical loadings from 0 to 55 lbs. A 6-inch diameter, 0.8-inch wide, solid polyurethane tire was loaded in 5-lb. increments and measurements were made of vertical deflection and contact patch geometry at each load. The deflection measurements were made using a standard machinist's height gage. The contact area was recorded by painting the tire with ink and loading it on a white sheet of paper.

Some interesting results of these tests are presented in Fig. 2, a plot showing the variation of footprint length with vertical deflection. Superposed thereon is a line corresponding to the equation

$$h/d = 0.85 \sqrt{(\delta/d) - (\delta/d)^2} ,$$

where h = footprint half-length, d = diameter, and δ = tire deflection, which has been shown by Smiley and Horne² to describe the behavior of representative aircraft tires. The agreement of the data with the curve is quite close, closer in fact than a good deal of the actual aircraft tire data shown in Ref. 2. This is indicative of a degree of geometrical similarity between the polyurethane model and full-scale pneumatic tires under vertical loading, a very heartening result since geometric similarity is a cornerstone presupposition in any straightforward scale modeling scheme.

Even given that the polyurethane tires will deform in a pattern geometrically similar to pneumatic aircraft tires (and this is yet to be demonstrated under dynamic conditions), it still must be shown that one can produce models with specific desired qualities, e.g., a particular static load-deflection curve. Figure 3 is a plot of load vs. deflection for two different 6-inch diameter, 1-inch wide, rectangular cross-section polyurethane tires, one with a bulk density of 10 lb/ft³ and the other 18 lb/ft³. It is seen that the variation of stiffness with density is substantial, with spring rates of 53 lb/in and 255 lb/in, respectively. Again using a geometric scale factor of 5:1 and a λ^3 force scaling law, these correspond to 1325 lb/in and 6375 lb/in, respectively, for tires 30 inches in diameter and 5 inches wide. Greater variations in density, and therefore spring rate, are also possible. Thus in light of the exploratory tests conducted to date, the use of the polyurethane tire models appears promising from both practical and theoretical points of view.

Some tentative decisions have been made regarding the sizes of model tires to be tested. Diameters will range between limits of 4 inches and 10 inches, established primarily on practical grounds such as characteristics of present apparatus, ease of handling, etc. It is practical considerations such as these which customarily determine the choice of

scale factor in a model experiment. In the present case, with the given limits and a scale ratio of about 5, the size range of existing aircraft tires is pretty well covered, and the speed requirements for the rolling road are reasonable.

Tire diameter/width ratios of from 1.5 to 4.5 are envisioned. These amply encompass the range found in present-day aircraft tires³.

The following table is one possible matrix of model tires satisfying the constraints established above. The tabulated quantity is width, with diameter and diameter/width ratio as parameters.

D/w \ D	4"	6"	8"	10"
1.5	2.70	4.00	5.33	6.67
2.5	1.60	2.40	3.20	4.00
3.5	1.14	1.71	2.28	2.86
4.5	0.89	1.33	1.78	2.22

The theoretical analysis of the idealized dynamic hydroplaning system, i.e., totally planing rigid body moving in shallow water at high Froude number, is continuing. The pair of integral equations describing this system has been reduced to a single Fredholm integral equation. This equation can be solved for the pressure distributions on the bottom (ground) and on the plate (tire) by application of known iteration techniques. The numerical solution is now being programmed in FORTRAN; simultaneously, however, an analytical procedure is being developed on the basis of a low aspect ratio assumption to obtain a solution of the integral equation in a closed analytic form.

On March 24, 1965, a team of DL personnel visited the NASA Research Center at Langley Field, Va., to discuss this program with Messrs. U.T. Joyner and W.B. Horne of NASA. The discussions proved to be extremely rewarding. In addition, the close-up observation of some Langley operations provided a valuable appreciation of the practical problems involved in this field.

On April 13, 1965, a letter⁴ was written to the NASA Office of Grants and Research to call attention to a discrepancy between the contract⁵ for this study and the proposal⁶ from which it stemmed. It was requested that a contract amendment or some other document be issued to clarify the discrepancy.

Plans for Next Quarter

Modification of the rolling road will continue. The installation of the new power supply and drive system will be completed. A 36-inch wide, .060" thick, oriented nylon transparent belt will be obtained and installed. A section of the rolling road's teflon support table will be cut out and replaced with plexi-glass, and a mirror system will be installed, to permit visual observation and photography of the tire footprint area. Construction of the tire rig and water film system will be completed. It is hoped that all modifications to the rolling road will be finished in this quarter, and that the test work will be under way.

Exploratory testing of the model tires will continue. Static tests will be made on polyurethane tires which are exact scale models of a 57x20 tire for which data are presented in Ref. 2. This will permit direct comparisons and, hopefully, the development of a relationship between pneumatic tire inflation pressure and polyurethane tire density. Static tests will also be made with commercial pneumatic and semi-pneumatic tires.

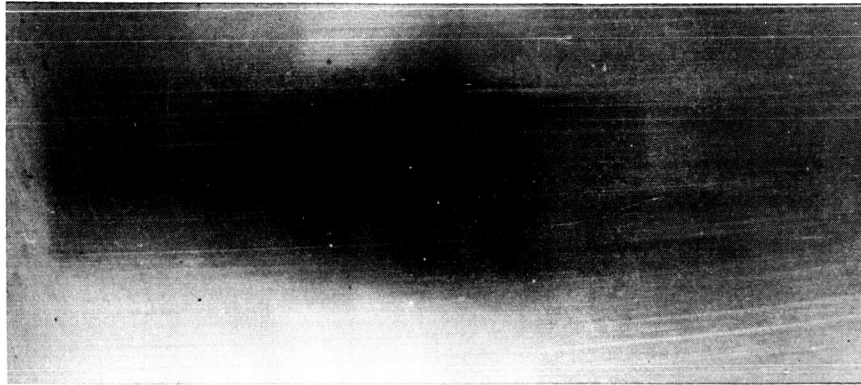
After the static tests are completed, the existing small tire rig will be installed on the rolling road, and exploratory dynamic tests will be run with polyurethane model tires. If the static tests with the semi-pneumatic tires are encouraging, dynamic tests will be run with these also.

The programming of the numerical procedure for the solution of the Fredholm surface integral equation will continue. The low aspect ratio solution of the problem will be pursued and numerical calculations for a given set of parameters will be conducted and results will be compared with those of measurements.

An inquiry was made of NASA as to the possibility of using one of NASA's IBM 7090 or 7094 computers to make the numerical calculations. No reply has been received to date, however, so tentative plans are being made to rent machine time from a commercial firm in the vicinity of Stevens.

References

1. First Quarterly Progress Report, Hydroplaning of Aircraft Tires, NASA Contract NSR 31003016, DL Project 475/6, 15 January 1965.
2. Smiley, R.F. and Horne, W.B., "Mechanical Properties of Pneumatic Tires with Special Reference to Modern Aircraft Tires", NASA TR R-64, 1960.
3. 1964-65 Year Book, The Tire and Rim Association, Inc., September 1964.
4. Letter, H.W. MacDonald, DL to Dr. Thomas J. Smull, Office of Grants and Research, NASA, 13 April 1965.
5. NASA Contract No. NSR 31-003-016, "Contract for Theoretical and Experimental Studies of Aircraft Tire Hydroplaning," October 15, 1964.
6. DL Proposal P-286, "Proposal for Research on the Hydroplaning of Pneumatic Tires on Wet Runways," 1 June 1964.



a. Tire Approximately $1/8''$ Away From Nylon Belt



b. Tire in Contact With Nylon Belt

FIG. 1 Photographs of Model Tire Taken Through Oriented Nylon Belt

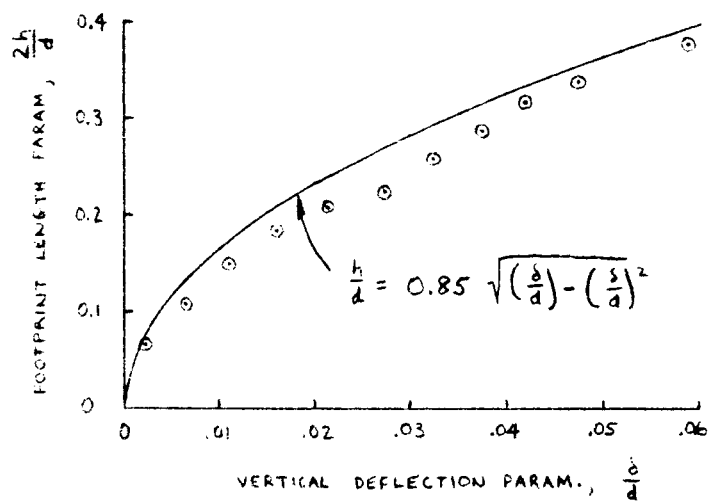


Fig. 2. VARIATION OF FOOTPRINT LENGTH PARAMETER WITH VERTICAL DEFLECTION PARAMETER FOR 6 IN. DIAM., 0.8 IN. WIDE SOLID POLYURETHANE TIRES.

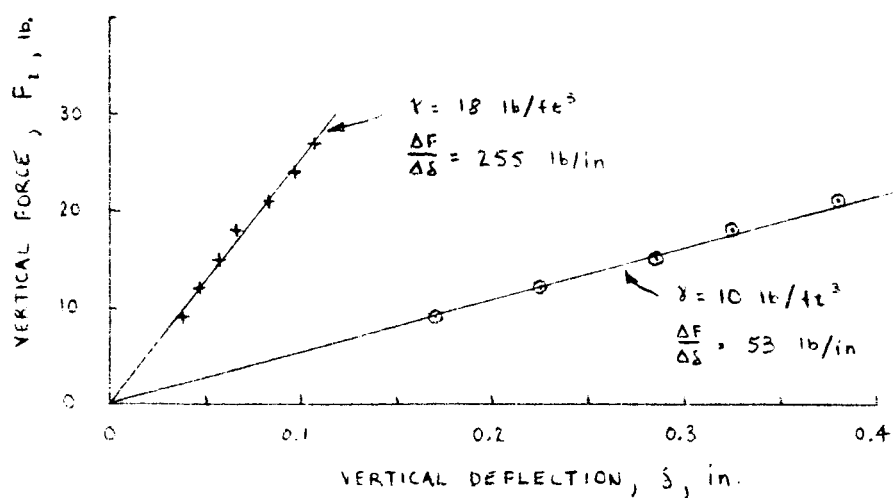


Fig. 3. VERTICAL FORCE-DEFLECTION CURVES FOR 6 IN. DIAM., 1.0 IN. WIDE SOLID POLYURETHANE TIRES OF 10 lb/ft³ AND 18 lb/ft³ DENSITIES.